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METHOD AND APPARATUS FOR
OPHTHALMOLOGICAL SURGERY

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RELATED CASE

This application is a continuation-in-part of copending application Serial No. 552,983, filed November 17, 1983, which will be abandoned.

BACKGROUND OF THE INVENTION

The invention relates to that aspect of ophthalmological surgery which is concerned with operations upon the external surface of the cornea.

Operations of the character indicated include
10 corneal transplants and keratotomies; such operations have traditionally required skilled manipulation of a cutting instrument. But, however keen the cutting edge, the mere entry of the edge into the surface of the cornea necessarily means a wedge-like lateral
15 pressure against body cells displaced by the entry, on both sides of the entry. Such lateral pressure is damaging to several layers of cells on both sides of the entry, to the extent impairing the ability of the wound to heal, and resulting in the formation of
20 scar tissue.

The CO₂ laser has been employed in an effort to minimize such surgical damage to cells on severed sides of a given cut, as in the case of operations to remove a local skin defect. The beam of such a laser is characterized by a particular infrared wavelength (10.6 microns), and controlled local ablation or incision of the cornea is achieved, without developing any lateral pressure upon cells adjacent to the margins of ablation. However, the operation is not performed without side effects, in that the ablation or incision is thermally achieved, through photo-coagulation and/or photovaporization; cells adjacent the ablated or incised margin are charred. And even with lasers emitting in the visible spectrum, the effect is still largely thermal in nature. For example, for visible laser irradiation of the skin at about 532.0 nanometers (0.532 micron), namely, in the pea-green portion of the visible spectrum, histological examination reveals evidence of cellular dehydration (i.e., cellular retraction with formation of tissue clefts, pyknotic nuclei) at energy densities where ablation can be accomplished; thus, at an energy level needed for ablation or incision with such radiation, charring (cellular damage) is observed at the site of the incision and is an indication of substrate heating.

On the other hand, radiation at ultraviolet wavelengths is characterized by high photon energy, and this energy is greatly effective on impact with tissue, in that molecules of tissue are decomposed on photon impact, resulting in tissue ablation by photodecomposition.

Molecules at the irradiated surface are broken into smaller volatile fragments without heating the remaining substrate; the mechanism of the ablation is photochemical, i.e., the direct breaking of intra-molecular bonds. Photothermal and/or photocoagulation effects are neither characteristic nor observable in ablations at ultraviolet wavelengths, and cell damage adjacent the photodecomposed ablation is insignificant.

CL BRIEF STATEMENT OF THE INVENTION

10 It is an object of the invention to provide an improved apparatus and technique for surgically operating upon the outer surface of the cornea.

Another object of the invention is to provide apparatus and technique for surgically modifying optical properties of the eye through surgical procedure on the outer surface of the cornea.

15 It is a specific object to provide surgical techniques and apparatus for reducing a myopic, for reducing a hyperopic, and/or for reducing an astigmatic condition of an eye.

20 Another specific object is to provide an improved surgical technique in performing corneal-transplant operations.

A still further specific object is to provide automatic means for safely applying ultraviolet irradiation in surgical procedures on the cornea.

The invention achieves these objects with apparatus which effectively fixes the position of an eye with respect to a scanning laser characterized by ultraviolet radiation, at an energy level capable of achieving

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controlled ablative photodecomposition of the cornea,
namely, of the epithelium, Bowman's membrane, and
stroma levels of the cornea. Irradiated flux density
and exposure time are so controlled as to achieve
5 desired depth of the ablation, which is a local
sculpturing step, and the scanning action is coordinated
to achieve desired ultimate surface change in the cornea.
The scanning may be so controlled as to change the front
surface of the cornea from a greater to a lesser spherical
10 curvature, or from a lesser to a greater spherical curva-
ture, thus effecting reduction in a myopic or in a hyper-
opic condition, without resort to a contact or other
corrective auxiliary lens technique, in that the cornea
becomes the corrective lens. The scanning may also be so
15 controlled as to reduce astigmatism, and to perform the
precise incisions of a radial or other keratotomy. Still
further, the scanning may be so controlled as to excise
corneal tissue uniformly over a precisely controlled
area of the cornea for precision accommodation of a
20 corneal transplant.

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DETAILED DESCRIPTION

The invention will be illustratively described in
detail, in conjunction with the accompanying drawings,
in which:

25 Fig. 1 is a schematic diagram in perspective, to
show the general arrangement of operative components
of the invention;

Fig. 2 is a simplified view in longitudinal section,
showing an eye-retaining fixture used with the apparatus
30 of Fig. 1;

Figs. 3 and 4 are simplified diagrams to illustrate different scan patterns performed with apparatus as in Fig. 1;

Figs. 5 and 6 are simplified sectional views to illustrate different sculptured surface curvatures achieved with either of the scan patterns of Figs. 3 and 4;

Figs. 7 and 8 are views in section, and Fig. 1 is a view in front elevation, to illustrate use of the invention in a corneal transplant operation;

Figs. 10, 10A and 10B are views in front elevation to illustrate use of the invention in different keratotomy operations;

Figs. 11 and 12 are, respectively, a view in front elevation and an enlarged half-section-profile diagram to illustrate a Fresnel-cut use of the invention;

Fig. 13 is a schematic diagram to illustrate apparatus modified to perform an astigmatism-correcting operation; and

Fig. 14 is a view similar to Figs. 3 and 4, to illustrate an astigmatism-correcting operation with the apparatus of Fig. 13.

In Fig. 1, clamp means 10 is shown for fixed retention of the head of a patient (reclined, face up) such that the eye 11 to be operated upon is fixedly aligned with a downwardly folded portion 12 of the central axis 12' of beam output from a stationary laser device 13, and scanner means 14 is provided for programmed deflection of laser-beam output, with respect to the central axis 12. The laser device 13 is served by a suitable power supply 15, and the scanner means 14

includes selectively operable control means, suggested
by legend, for determining scan pattern, effective
limits of scan action, and, if desired, the time-
varying profile of one or more dimensional components
5 of scan action.

Preferably, the clamp means 10 includes means,
symbolized at 17, to stabilize the patient's head via
opposed engagements at the region of his temples, and
an eye-retaining fixture (18, Fig. 3) peripherally
10 engages eye 11 at the corneal-scleral area. Also
preferably, an optical-fixation device 20 is adjustably
fixed, as to the housing of scanner 14. Illustratively,
device 20 includes a sighting reticle and lens, whereby
40 the eye 11' not being operated upon can view the reticle
15 as if at infinity; the sighting alignment 21 for device
20 is parallel to the axis 12, and it will be understood
that adjustable means (not shown) may provide an adjust-
3 able offset, as needed for accommodation of the patient's
interpupillary distance and to adapt to the particular
20 mounted offset of device 20 from axis 12. For an opera-
40 tion on the other eye 11', the eye 11 will be available
for similar fixation, in conjunction with another fixation
device (not shown) and associated adjustably offsetting
means; alternatively, the fixation device 20 may be
25 adjustably mounted at correct offset on the opposite
side of scanner 14. For purposes of operating on eye
40 11', clamp means 10 will have been indexed laterally
with respect to laser 13 to the extent aligning axis
40 12 with the eye (11') then to be operated upon, thereby
30 positioning eye 11 for use of the fixation device.

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The eye-retaining fixture 18 of Fig. 2 is seen to comprise a hollow annulus, having a convergent axial-end wall 23 of air-permeable material contoured to engage and retain the eye via a scleral-corneal region. A side-port connection 24 to a vacuum pump enables retention of eye engagement to wall 23, and outward lug or flange means 25 enables rigid aligned and spaced connection of fixture 18 to laser 13 and its scanner 14 via means suggested by legend in Fig. 2, such means being omitted from Fig. 1 for reasons of more simplified showing.

The laser selected for use at 13 preferably emits in the ultraviolet, namely, at wavelengths of less than substantially 400 nanometers. Such emissions for gas lasers are characteristically at 351 nm for xenon-fluoride lasers, 337 nm for nitrogen lasers, 308 nm for xenon-chloride lasers, 248 nm for krypton-fluoride lasers, 193 nm for argon fluoride lasers, and 157 nm for fluorine lasers; and within this range, frequency-doubling techniques applied to other lasers, including crystal lasers, provide further alternative sources.

One of the existing commercial excimer-laser products of Lambda Physik GmbH, Gottingen, Germany, for example their Model EMG 103 operating with argon-fluoride, is satisfactory for use as laser 13; for this product, maximum energy per pulse is 200 millijoules, with a pulse-repetition rate of 200 per second, 3×10^5 shots being available from a single charge of the involved gas, before reducing to 50 percent of specified power at this repetition rate, it being noted that full rated power

is not necessarily required in use of the present invention. Pulse width is about 15 nanoseconds, and typical beam dimensions at 25 centimeters (10 inches) are 10 mm x 22 mm. To bring this down to an illustratively useful rounded-square spot size of 0.5 mm by 0.5 mm at the eye 11, corrective lens elements at 26, as of quartz, calcium fluoride, or magnesium fluoride, will be understood to include a cylindrical element and a spherical element whereby beam size is reduced while the rectangular section is compressed to substantially square section.

Figs. 3 and 4 illustrate alternative scan patterns for having the typical half-millimeter focused and repetitively pulsed spot of the laser beam course the surface of eye 11 in the performance of a surgical procedure. The circle 30 in Fig. 3 may illustratively be of 6-mm diameter at the cornea, and centered on the axis of eye 11. The scan action is rectilinear, involving plural horizontal line scans with progressive vertical displacement to cover the field, here shown limited to the circle 30. For this purpose, a suitable scanner, known as "Microscan 771", is commercially available from Laser Industries, International, Hendon, England and therefore need not be here described in detail. It suffices to say that the control means 16 associated with such a scanner includes a microprocessor with memory for delineated boundary limits of scan, such as the limiting circle 30. The delineation can be to the surgeon's desired boundary contours, and the scan speed and direction may be programmed or manually controlled.

What has been said as to Fig. 3 also applies to Fig. 4, except that a spiral course of scan, i.e., rotary sweeps at progressively changing radius, is involved in each coverage of the delineated field
540 30'.

It is a feature of the invention that the programming of scan action be such that predetermined depth of ultraviolet laser incision be made to effectively recharacterize the external contour of
10 the cornea within the entire predetermined field
40 boundary (e.g., 30, 30'). This is done by progressive precise photodecomposition of the corneal tissue, as to a depth limit of 0.35 mm. In the illustrative argon-fluoride laser referenced above, a precise
15 volume of tissue (e.g., 14 microns deep) may be excised for each laser pulse or shot, and the half-millimeter spot, repeated at 200/second, can cover the entire area within the delineated boundary 30, in about fifteen seconds.

20 For the situation depicted in Fig. 5, the dashed line 31 represents the ultimate curvature to which the external surface of a cornea 32 may be modified to achieve a change in optical properties of the involved eye, here illustratively a myopic eye, for which the
25 reduced curvature 31 offers a diopter-reducing corrective effect, all without resort to the use of a spectacle lens or a contact lens to achieve the result. To achieve the curve 31, the minimum desired photodecomposition is at the outer boundary 30, and the maximum is at the center.
30 This is achievable by programming the microprocessor to

progressively reduce the radius of the boundary circle 30 (i.e., progressively reduce the area of scanned field), for successive scans of the reducing field. If the curvature 31 requires a maximum depth
5 of 0.35 mm of cornea removal at the center, this means that the central region of the cornea (i.e., the last and most reduced scanned field) will have been scanned twenty-five times, and that cornea removal outside this most reduced scanned field will
10 have involved lesser numbers of scans, the progression having been predetermined to achieve the desired ultimate curvature 30 over the area 31.

What has been said as to the scan technique of Fig. 3 to achieve curvature 31 applies equally for
15/40 use of the spiral scan of Fig. 4, the field 30' again being programmed for automatic reduction as necessary to provide maximum cornea removal at the center, and minimum at outer limits of the circular boundary.

What has been said as to programming to achieve
20 lesser curvature in the outer surface of the cornea (Fig. 5), to reduce a myopic condition, applies also to Fig. 6 for reduction of a hyperopic condition. In Fig. 6, the difference lies in programming field scans so as to initiate and progressively enlarge a central
25 area which defines the inner limit of field scanned. Thus, except for perhaps one field scan involving cornea removal over the entire area bounded by circle
40 30 (30'), all remaining field-scanned areas are annular, with progressively increasing inner radius of each
30 successively scanned annular field. The last such

"field" will necessarily be virtually a circular
40 line at the diameter of circle 30 (30'), along
which circular line the depth of surgical excision
will have been greatest, as indicated by dashed
5 line 33 in the cornea 34 of Fig. 6.

Quite aside from the variable-depth character
of the removal of corneal tissue (Figs. 5 and 6),
the invention also lends itself to uniform-depth
removals, over the entire area of a multiply-scanned
10 constant field. In Figs. 7 and 9, the cornea of an
eye 11 is subjected to a succession of scans of
(i.e., within) a constant predetermined field area 35.
In the illustrative laser case, with excision to a
depth of 14 microns for each pulse, a uniform depth
15 of 0.35 mm is achieved by 25 scans of the total area
34, to produce a carved base or floor curvature 36
for reception and location of a corneal transplant.

Further with respect to a corneal-transplant
procedure, the described apparatus will be seen to
20 be further useful, as in preparation of the corneal
insert to be implanted at and within the recess 36.
A donated eye may be reversibly held to a fixture as
described at 18 in Fig. 2; by "reversible" it is
meant that, depending upon the manner of mounting
25 flange 25, either the epithelium or the endothelium
of the donated eye may be mounted for upward exposure
to the laser beam 12, it being understood that for the
latter situation with the donated eye, iris and other
regions not needed for corneal-scleral mounting and
30 for corneal operation will have been initially removed.

A preferred procedure is first to so expose to laser scanning the concave inner side of the donated cornea; such scanning is to an extent (achieved by multiple scans of a full circular field exceeding the diameter of recess 36) sufficient to remove tissue at least to a uniform depth within the stroma, whereupon the mounting of fixture 18 (and its partially machined corneal workpiece) is reversed, to expose to laser scanning the convex outer side of the donated cornea. Scanning the outer side consists of two steps: first, multiple scans of the full circular field (exceeding the diameter of recess 36), thereby excising at least the epithelium and to a depth which preferably achieves a transplant thickness T_1 exceeding the depth T_2 of recess 36; second, scanner 14 is operated in a line-cutting mode wherein successive laser pulses sequentially advance along the circumference of a circle designed for precise acceptance in the circular recess 36, until full severance of the circular cut-out, which then becomes the prepared transplant. Upon implanting, donated stroma is placed in full endothelium³ free contact with the patient's prepared stroma, and the implant may be sutured. Later, upon removal of sutures, the outer surface of the eye 11 and its transplant 27 will have the appearance shown in Fig. 8, wherein the transplant projects beyond adjacent areas of the patient's cornea, and this projecting surface of the transplant may be reduced by laser

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scanning to a finish contour 28 of preferably flush
marginal conformance with non-sculptured adjacent
3 tissue of the patient's eye. It will be further
3 understood that, subject to the surgeon's decision,
5 such a finishing cut may be to a curvature which
does or does not effect a predetermined change in
optical performance of the eye.

Fig. 10 illustrates a modified use of the
described apparatus, as for developing the plural
10 angularly spaced radial cuts 37 involved in a radial
keratotomy, all within a predefined circular limit
38. Depending upon the severity of the condition
which calls for a keratotomy procedure, the depth
of radial cuts 37 may exceed the 0.35 mm depth
15 illustratively given for Figs. 5 to 8.

Certain myopic and hyperopic conditions may be
so severe that to produce merely an excised single
3 surface 31 or 33 could involve, in the surgeon's
considered judgment, an excessive removal of tissue,
20 at the involved region of necessarily deepest cut.
For such a situation, the invention offers the option
of programming successive scans in a manner to create
a Fresnel-type stepped development of the desired
ultimate curvature. Such a situation and procedure
25 are illustrated in Figs. 11 and 12, wherein an ultimately
reduced-curvature surface 31 of Fig. 5 (dashed
line 41 in Fig. 12) is achieved in annular increments
within the field area bounded at 30. In the outer one
of these annuli (42), the curvature and depth of cut
30 are precisely as would have applied to generate the

continuous curve 41 (i.e., without Fresnel steps).
But the intermediate annular area 43 effectively
achieves a continuation of curve 41 with much less
volume of corneal excision. Finally, the inner
5 circular area 44 effectively completes curve 41,
with minimal removal of corneal tissue.

The removal of tissue at the center is denoted
 Δ_{44} for the Fresnel cut 44 of Figs. 11 and 12 and
comparatively, is but a small fraction of the maximum
10 removal depth Δ_{41} which would be needed to achieve
the same optical correction with the smoothly developed
corrected single-curvature surface 41. It will be
understood that for the Fresnel-type cut as illustrated
in Fig. 12, the previously described illustrative half-
15 millimeter spot size will be incapable of achieving the
desired result, for the one-millimeter radial increments
shown in Fig. 12. To produce the requisite resolution
for characterizing increments of curvature 41 at 42,
43, 44, it is necessary to employ a smaller spot size.
20 For the indicated Lambda Physik equipment, spot-size
reduction is feasible via means 26 as far as to produce
a 30-micron spot size, if necessary; with this capability,
it is seen that the one-millimeter radius increments
of annulus 42 and annulus 43 are each achievable with a
25 resolution of about 35 radial steps per increment (42 or
43). It will thus be understood that numbers given above
are for purposes of more simplified illustration of this
and the other aspects of the present invention.

In the discussion thus far, an excimer laser has
30 been the illustrative source of an ablating beam, and

it has been generally indicated that other lasers are available as alternative sources in the desired ultraviolet region and at presently suitable energy levels, and these other lasers will emit continuously for periods of controlled duration. For example, an organic-dye laser utilizing the proper organic dye can be made to produce laser emission in the region of 380 nm when pumped by an ultraviolet laser source such as a continuous-wave neodymium-YAG laser operating at 266 nm; in this case, the organic dye laser emission at 380 nm can be frequency-doubled by a proper non-linear crystal such as a potassium titanium-phosphate (KTP) crystal to an emission wavelength of 190 nm.

The showing of Figs. 1 to 5 will thus be understood to illustrate the further case wherein ultraviolet laser radiation on axis 12 is of continuous wave nature, for programmed exposure and scan control at 15, such that the per-unit time exposure of a given element of scanned area on a given scan-deflected pass of the elemental area involves beam-exposure flux at a level at which resultant corneal-tissue ablation per scan is to an ascertained elemental depth which is but a fraction of desired maximum ablation into the stroma region of the cornea. The desired maximum ablation therefore results from programmed exposure to successive continuous-wave scans of the local area requiring deepest incision, to effect the desired corrected anterior-surface profile of the cornea. And it will be understood

that continuous-wave scanning is also equally applicable to the various sculpting purposes and techniques described in connection with Figs. 7 to 12.

5 Figs. 13 and 14 illustrate applicability of the invention to the correction of an astigmatism which has been identified in a particular eye. In this situation, the anterior surface of the untreated eye exhibits a cylindrical component
10 of curvature which is a departure from otherwise generally spherical curvature, and the orientation of the axis of cylindrical curvature is at a particular angular orientation α with respect to the central vertical axis of the eye. Fig. 14 indicates.
15 this angle α in the context of a circular area of perimeter P to be subjected to astigmatism-correcting laser-scanning ablation. For the depicted illustrative case, area scanning of progressively changed areas utilizes a rectilinear X-Y coordinate drive 50 of
20 scanner 14, wherein the orientation of the X-Y coordinate system can be angularly adjusted by selectively operable means symbolized by a knob 51
60 having associated means 52 to indicate the angle- α setting appropriate to the eye 11 requiring correction.
25 The X-Y coordinate scan drive 50 is shown under control of microprocessor means 53, with indication that means 53 is programmable to govern a sequence of
60 scanned areas, at the preset angle α .

For discussion purposes, it is indicated in
30 Fig. 14 that adjusted angular displacement of the

X-Y components of scan action establishes the line-
scan orientation L for the line-scan component and
the transverse offset S for the line-displacement
component of rectilinear scan, plus and minus
5 directions being shown for the transverse offset S,
with respect to a central alignment of symmetry in
the L direction. Pulse-control or gating means 54
is shown with input connections from the scan-drive
means 50 and from microprocessor means 53, and with
10 an output connection 55 to determine gated on/off
control of laser output in the course of area
scanning.

More specifically, and assuming the case of
progressive reduction of scanned areas to reduce
15 the astigmatism, a first area scan may be effected
by a succession of parallel L-oriented sweeps, at
incremental advance of transverse offset S, commencing
31 with a first short chordal sweep $-S_1$, and progressing
across almost the full circular area (within perimeter P)
20 until termination of the first area scan at the symmetri-
cally opposite short chordal sweep $+S_1$, thereby ablating
a first slightly truncated area (within perimeter P) to
a first incremental depth in the cornea. On the next
area coverage, the limiting outer parallel truncations
31 30 25 $-S_2$ and $+S_2$ apply, to create a second area of incremental
ablating intrusion which symmetrically laps (and is
therefore cumulative with) all but the outer increment
of truncations, from $-S_1$ to $-S_2$, and from $+S_1$ to $+S_2$.
In like fashion, successive area scans are at pro-
30 gressively shrinking spans between symmetrically

31 30 inwardly displaced parallel truncations, $-S_3 (+S_3)$,
and so on, until the final area scan is of line or
virtually line thickness, namely, when scanning the
laser beam essentially only on the central axis of
5 symmetry, on axis L. The net result of cumulative
ablation is to achieve desired maximum depth of
sculptured cut on the central axis of symmetry, at
the preset orientation α , with depth of cut which
gradually reduces to a minimum at the outer trun-
31 20 10 cation lines $-S_1 (+S_1)$. It will be understood that
the sculptured profile of cut may be cylindrical,
to the extent of effecting a prescribed number of
diopters of cylindrical correction, depending upon
the programming of scan-area reduction predetermined
15 at 53. And it will be further understood that the
same kind of cumulative ablative sculpture to achieve
a cylindrical-surface correction can be obtained for
a program of successive-area scanning wherein the
first-scanned area is narrow and on the central axis
20 (L) of symmetry, with area-expansion between widening
limits of the parallel truncations, to the point of
finally scanning at the shortest and outermost trun-
31 20 cations $-S_1$ and $+S_1$ of the area described by perimeter
P.

25 In use of the invention for laser surgery upon
an eye having need for both astigmatic and spherical
correction, it is preferred that the astigmatic
correction, described in connection with Figs. 13
and 14, be the first of two procedures. This is
30 considered advantageous because astigmatic errors

are generally not as severe as spherical errors, so that fewer diopters of cylindrical-curvature ablation will be involved than for the subsequent spherical correction procedure. Furthermore, to have eliminated or substantially eliminated the astigmatism in a first procedure is to have constituted the anterior surface of the cornea to an essentially spherical surface, which (be it myopic or hyperopic in nature) is more assuredly correctively sculpted to the desired profile (also spherical) for emmetropia vision, particularly where, as is the case of this invention, all ablative laser area scans are effectively centered on the optical axis of the eye.

It will be seen that the described methods and apparatus achieve all stated objects and provide readily controlled procedure for correcting eye abnormalities attributable to cornea curvature. The ablative penetration of laser beam action may be kept to a relatively harmless fraction of the thickness of the cornea, and whatever the depth of invasion, a natural body process provides protective epithelium coverage of the sculpted region, within a few days after an operation. The programmable coordination of scan-area size and shape (circular, annular, or truncated) in conjunction with unit-time exposure at given sizes and shapes will produce predictable and controlled changes in curvature, whereby cylindrical errors and/or spherical errors may be eliminated or substantially reduced, to the enhanced comfort and convenience of the patient.

While the invention has been described in detail for various illustrative embodiments and modes, it will be understood that modifications may be made without departing from the scope of the invention.

5 For example, what has been described above as manual means 51 to preset the angle at which astigmatic correction is to be achieved, may in fact be an automatically driven setting of the astigmatic correction angle, wherein the angle-input data for making the automatic drive is produced by a diagnostic system or method as described in my copending patent application, (Serial) No. 691,923, filed (January) 16, 1985.

Also, it will be understood that, although preferred, it is not necessary to limit area-scanning to the circular perimeter P when sculpting for astigmatism correction. The circle perimeter P represents a preferred minimum area of ablative sculpture, being that maximum circular area involved for sight under dilated-pupil conditions, e.g., about 7-mm diameter. However, the corneal-area outside this perimeter P is not required for best central sight and therefore no optical-related harm results if the scanning procedure is such as to ablate in regions outside perimeter P. Thus, in Fig. 13, it is not strictly necessary that pulse-control means 54 shall have the "envelope limiter" (i.e., perimeter P limiting) function suggested by legend. In other words, a purely rectangular accomplishment of all area scans, from a "single-line" area on the axis (L) of symmetry to outer limits $-S_1$ and $+S_1$ of successively expanding scanned rectangular

areas, will accomplish the same optical result, at perhaps a slight degradation of cosmetic appearance.

Still further, it will be understood that the radial keratotomy described in connection with Fig. 10 is illustrative of but one of a variety of keratotomy procedures to which the invention is applicable. For example, because of the great precision with which laser scan action can be microprocessor-controlled, the keratotomy may include concentric-circle loci of ablative incision, and the circular incisions may be full-circle or in a distributed pattern of circular arcs, in angularly interlaced array, as shown in Fig. 10A, the full circles or the circular arcs being with or without connected or disconnected radial incisions, as the surgeon may deem best for his particular patient's purposes. Also, as illustrated in Fig. 10B, a radial keratotomy may be implemented, again with microprocessor control of scan action with further incisions (as at 60) transverse to, and preferably not intersecting with, a particular orientation of radial incisions 61, where the radial incisions 61 are oriented to accord with the axis for which an astigmatic correction is to be made.

CM What is claimed is:

Claims